AREAS OF RECURRENCE OF TOXIC ALGAE WITHIN BURRINJUCK DAM, NEW SOUTH WALES, AUSTRALIA

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ABSTRACT

May, Valerie (National Herbarium of New South Wales, Royal Botanic Gardens, Sydney, Australia 2000) 1978. Areas of Recurrence of Toxic Algae within Burrinjuck Dam, New South Wales, Australia. Telopea 1 (5):295–313—Potentially toxic algae (*Anacystis cyanea* and/or *Anabaena circinalis*) occur periodically as unwanted summer blooms on surface water of Burrinjuck Dam. Examination of Bottom water collections from routine stations within the dam showed that *Anacystis* occurred near the junctions to the dam of each of the three river arms, but that in regions near the junction of both the Murrumbidgee and Yass River arms it occurred earliest, most frequently, more densely and persisted longest. These two general regions also appear to be suited to the regeneration of *Anabaena*. The water from both these regions contrasts with that from the corresponding region near the junction of the Goodradigbee River arm in that it is richer in phosphorus, nitrite and ammonia nitrogen, iron, potassium and bacteria; also it is much lower in oxygen content and shows less light penetration. These nutrient-rich regions receive sewage and drainage effluent from upstream settlements as well as more run-off from pastoral and agricultural land, which could well account for the contrasting physico-chemical conditions. The resultant abundance of *Anacystis* in both these regions is considered a source of potential algal blooms and it is therefore concluded that these productive zones are the ones that should be treated in any attempt to control or inhibit algal blooms in the dam.

INTRODUCTION

Burrinjuck Dam is a man-made water impoundment situated in the western slopes area of New South Wales at 35° 00′ S, 148° 35′ E. It is fed by three rivers, the Murrumbidgee, Yass and Goodradigbee; the first two of these drain relatively populated and developed areas, while the third runs through relatively undisturbed areas.

During the last few years problems have developed at this water reservoir because of the increasing amount of summer-time water blooms of the blue-green algae *Anacystis cyanea* (Kuetz.) Dr. & Dail.* and *Anabaena circinalis* Rabenh., either separately or together. These algae occur in nuisance quantities and they can be toxic (McBarron and May, 1966, and May and McBarron, 1973). Although it is known that the degree of toxicity of these algae varies (Gorham, 1964), the risk of toxicity exists; throughout this paper the term "toxic algae" also includes potentially toxic algae.

The present work was undertaken over a period of three years (40 months) primarily to study the development of these blooms and to determine the likely causes and location of their occurrence. This information could lead to the possible control or modification of the blooms.

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* Also known as *Microcystis aeruginosa* Kuetz.

METHODS

Samples of both surface (Top) and near-sediment (Bottom) water were collected each month. The number of stations examined has been progressively increased during the survey; three sampling stations were used initially (between February, 1972, and August, 1973), and then a further three were added to provide a better coverage of the total water area (Figure 1, stations 1–6). For greater precision, additional Bottom stations were examined (11 collection dates) between June, 1974, and April, 1975 (Figure 1, stations 13–20). Further collections were carried out by T. Scribner (N.S.W. State Fisheries) in November, 1973, and 1974, and February, 1974, and 1975: these are considered also in this study.

At each sampling station at each time of collection the water depth was recorded, the temperature of the Top and Bottom water measured and the amount of light penetration through the water estimated. The algae recovered at each such station were examined from both live and formalin samples. In addition, bacterial counts were made on samples from Stations 1 to 6 (since 8.1973) and analyses of the phosphate, ammonia nitrogen and potassium content of the water carried out. Further, Scribner investigated also the dissolved oxygen content, the iron and the nitrite nitrogen content of the water from the more numerous stations from which he collected.

OBSERVATIONS ON GENERAL FLORA

Algae Observed at Burrinjuck Dam

Altogether 31 species of algae are recorded from Burrinjuck Dam. Some occurred infrequently (Table 1A), while others were more common (Table 1B) or at times dominant (Table 1C).

Of the 17 species listed in Table 1A, more than one half (10 species) were recorded at one or more stations (in both Top and Bottom collections) in October or November, 1974, following a period of excessive flooding, when the heavy flow of water had disturbed the normal algal distribution in the dam. Thus the occurrence of these species may be linked with variations in rainfall and run-off.

Most of the species listed in Table 1B show some seasonal variation.

Some species, including *Ankistrodesmus falcatus*, *Ceratium hirundinella*, *Closterium* sp. and *Pandorina* sp., occurred less frequently or not at all during the peak of summer. *Melosira granulata*, *Oocystis* sp., *Staurastrum* sp., *Sphaerocystis schroeteri* and *Trachelomonas* sp. showed little seasonal variation. *Melosira varians* was rare or absent in July to October.

Cyclotella sp. occurred as a slight bloom at Stations 3 and 5 in October, 1974, following the flood, and was moderately common also in most Bottom stations at this time. *Micrasterias hardyi* occurred mainly from February to August, both in Top and Bottom collections, but was frequent only in the Bottom collections of March, 1975.

The toxic species, *Anacystis cyanea* and *Anabaena circinalis*, were at times dominant; details of their occurrences will be further considered below.

At Burrinjuck Dam, the richness of flora varied throughout the period of study. In some cases new records in a station were due to redistribution of species by flooding. It seems that the period of three years study was insufficient to remove the effects of such chance changes, and hence no consistent picture of the area of the greatest number of species has emerged.

Comparison with Earlier Work

The only comparable earlier study of algae in a large dam in Australia is that of West (1909) at Yan Yean Reservoir, Victoria. West carried out plankton trawls and collected from shore areas in an attempt to study the whole flora of the dam. While the aims and methods of his study differed from the present ones, certain comparisons with his data are worthwhile. Thus, of the phytoplankton recorded here from Burrinjuck Dam, nearly two-thirds of the genera (18/29) occur also at Yan Yean: a number of the species are the same.

As at Yan Yean (West, 1909) diatoms, except *Melosira*, were not a conspicuous part of the flora. However, unlike Yan Yean in 1905–1906, the blue-green algae in Burrinjuck Dam in 1972–1975, were at times the dominant algae, occurring as blooms. In Yan Yean Dam the phytoplankton density was at a maximum in March-April with a minimum in September-October. In Burrinjuck Dam the maximum occurred between November-February, when many blue-green algae developed. September-October has tended to be a time of flooding and therefore the density of plankton was variable.

OBSERVATIONS ON THE TOXIC ALGAE

Anacystis cyanea and *Anabaena circinalis*, the species of main interest in this study, are found in either Top and/or Bottom water samples (Table 1C) and sometimes occur as surface water blooms in summer: these are likely to be dense between November and February. These toxic algae can appear under very similar conditions and, within a single floating surface bloom, are able to replace each other in Top collections by changes in their relative frequency. This happened at Burrinjuck in the summer of 1973–74, where the bloom started as *Anabaena* (occurring from July, 1973, to February, 1974) and finished as *Anacystis* (occurring from November, 1973, to August, 1974), with a dense mixed bloom from November to February (Table 2).

Since distribution of the surface water blooms can be affected by local wind and water movements, Bottom sampling was considered more reliable than Top to provide information on areas of development and seasonal regeneration of these species. It seems likely that those areas where there is evidence of dense, frequent or early occurrence of the toxic species in Bottom collections are those areas from which regeneration is most likely to occur, perhaps from resting stages in or on the mud. Collections during or immediately following a dense bloom could be less helpful since the surface bloom, occurring where the wind blew it, could also provide additional specimens in Bottom collections (when the dam was not stratified or by contamination during sampling). These could be relatively random in distribution. Residual surface occurrences are likely to be found at any time, being sometimes quite slow in disappearing. The actual month of the year when the algae start to re-develop appears to vary from year to year, being affected, for instance, by floods.

Occurrence of *Anabaena circinalis*

Prior to the summer of 1973–74, the earliest Bottom collections of *Anabaena* were found at Station 3 in the Murrumbidgee Arm in July, 1973, and at Station 6 in the Yass Arm in August, 1973, while other stations showed no such occurrences. Immediately prior to July, 1973, no surface bloom was reported.

During the summer of 1973–4 (October to March), this species was plentiful throughout the reservoir, being part of a surface bloom from November until February (Table 2). During this time it was recorded in 10 Top collections at 5 different stations and in 8 Bottom collections at 6 different stations.

After a winter period during which the species was found only in isolated, possibly residual, Top collections (at Stations 1 and 6 in May, 1974), *Anabaena* reappearing sparsely in a Bottom collection at Station 14 in July, 1974. Flooding, which commenced in August, 1974, seemed to have suppressed the summer development of the species and, after the flood, unlike *Anacystis*, *Anabaena* did not recur quickly. It has been found since then only at Stations 6 and 4 in March, 1975, and June, 1975, respectively.

There is no evidence of *Anabaena* occurring in quantity in any particular Bottom area. No doubt it overwinters in its spore form and regenerates in favoured positions, although not speedily following flooding. Heterocysts were present in October and November, 1973, in February, 1974, and in March, 1975, i.e. during the main summer bloom period.

Occurrence of *Anacystis cyanea*

Anacystis was first observed in the reservoir at Station 1 (Top collection) in October, 1973 (Table 2), and thereafter developed very rapidly throughout the reservoir, being present in all Top collection samples between December, 1973, and February, 1974, and being part of the dense surface summer bloom which occurred between November, 1973, and February, 1974. The species did not finally disappear from Top samples until after August, 1974.

Bottom collections indicated *Anacystis* was well distributed throughout the stations between November, 1973, and April, 1974, (Table 1C). During this time of extensive heavy bloom, the number of records of *Anacystis* from Stations 1 and 2 Bottom water was higher than at any other period of the observations.

In May *Anacystis* was limited to Station 6 in Bottom collections, although Top collections recorded it at Stations 1, 5 and 6.

Occurrences of *Anacystis* in Bottom collections after May, 1974, until April, 1975, (including the additional collecting stations, see Figure 1), are shown in Table 3. In June, 1974, Bottom collection *Anacystis* was found in Stations 3, 5, 20, 14, 6, 19 and 18, together with a trace in Station 1. The latter was probably due to blocking of the current by the dam wall and hence could be ignored. The heaviest occurrences were from Stations 20, 6 and 19. Top collections came from Stations 1, 4 and 6. The affected Bottom stations were all near the junctions of each of the three rivers with the main body of the dam (Figure 1); but the Murrumbidgee and Yass River arms showed a much higher incidence than did the Goodradigbee. Of the two samples (fresh and with formalin) from the same level of those stations near each

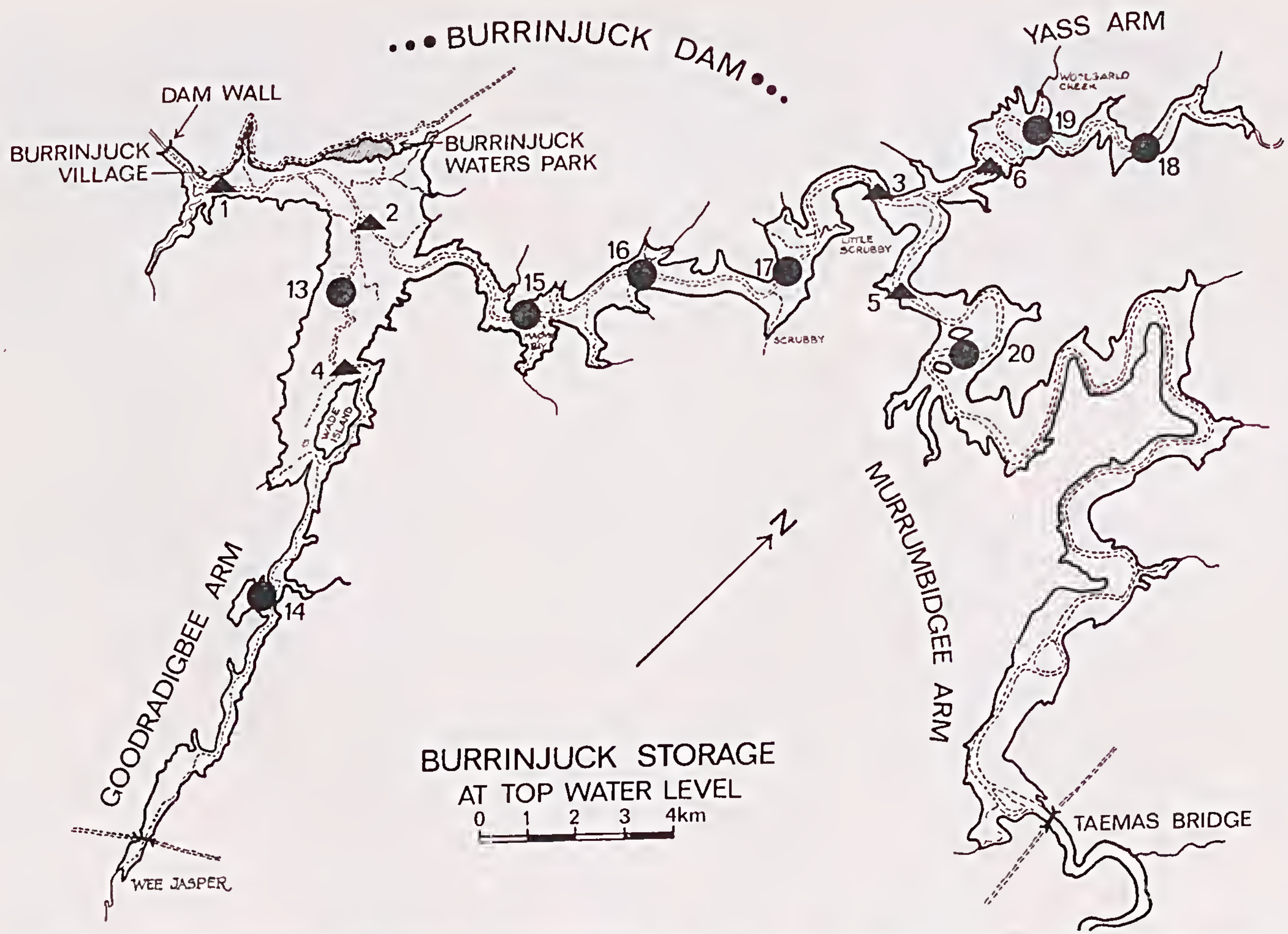

Fig. 1. Map of Burrinjuck Dam showing the stations used for the present study. The basic stations 1 to 6 are marked by triangles, while the later additional Bottom collection stations 13 to 20 are marked by circles.

river junction taken from a depth of about 12–40 m, *Anacystis* occurred in four of a possible six cases in each of the Murrumbidgee and Yass areas, but only one in six in the Goodradigbee collections. *Anacystis* did not occur further downstream from the two most affected river arms, even though the depths were similar to those stations in which it did occur.

In July, 1974, *Anacystis* occurred in Bottom collections from Stations 20, 4, 14, 6, 19 and 18. Heavy flooding had commenced by August, earlier in the Murrumbidgee arm, and this affected the collections, causing a marked decrease in algal content in the water. This flooding was accompanied by heavy overflow from the dam and no doubt removed quantities of both algae and sediment. At the peak intensity of the flood (late August, 1974) it was reported that the water volume of the dam was being replaced every three days. The toxic algae (*Anacystis* or *Anabaena*) were absent from all samples collected in September and October (the only time such absence was recorded during detailed observations). This doubtless means that the dilution was too great for the collection bottles to be likely to obtain specimens. This flooding interrupted the normal seasonal development of the toxic algae.

Regeneration after the flood occurred in the same areas as in June, 1974, i.e. near the junction of each of the three rivers with the main body of the dam. In November, 1974, *Anacystis* occurred rarely in the Bottom sample from Station 3. Floating (Top) material was not noted until December, indicating that Bottom collections following the flood were not affected by surface occurrences. In an extra survey (comprising twelve stations, with forty collections throughout the dam) Scribner (14th November, 1974), recovered *Anacystis* (rare) from a single surface collection situated above Station 20 in the Murrumbidgee River.

In December, 1974, *Anacystis* was found (rare) in Bottom collections from Station 13 (Goodradigbee) and Station 6 (Yass), while Top collections of it came from Stations 2, 4 and 6 (also only rare).

In January, 1975, it was found more widely distributed, occurring in Bottom collections at Stations 3, 5 and 20 (densest in the latter) in the Murrumbidgee area, Stations 4, 14 (both rare) in the Goodradigbee area, at Stations 6, 19 and 18 (rare) in the Yass area, and at Station 2 (rare) of the main dam. It occurred also in surface collections at Stations 3, 5 and 6 (densest in the latter) and also at Station 1 (rare).

The rare occurrences in Station 1 (Top) and 2 (Bottom) could be considered due to *Anacystis* being washed down and perhaps dropped as the current lessened due to the effect of the dam wall.

February collections showed *Anacystis* present in all surface samples, and in some wind-concentrated areas it occurred as a dense bloom. At this time *Anacystis* occurred in the Bottom collections only in the Murrumbidgee and Yass arms and downstream below Station 3 in the main dam (i.e. Stations 5, 15, 16, 6, 18 and 19). Scribner, in a further survey (February, 1975) of his stations obtained *Anacystis* in Bottom collections only from near the junctions of the Murrumbidgee and Yass arms; surface collections of the species were more widespread.

By March, *Anacystis* was found only in Bottom collections from the Murrumbidgee and Yass arms areas (Stations 3, 5, 20, 6, 18 and 19), and in April was recorded only from Stations 20, 6 and 19. A further cycle appears to have started in May with *Anacystis* at Stations 2 and 3, and at Stations 2, 3 and 6 in June, 1975. Surface collections were obtained at Stations 3 and 6 in May, but not in June, 1975.

More Frequent Occurrences of *Anacystis cyanea*

The most frequent records of the occurrence of *Anacystis* in Bottom collections throughout the study were from Station 6, near the junction of the Yass River with the main body of the dam (11 times), and Station 3, near the Murrumbidgee River junction (10 times); these were the stations at which this alga developed early seasonally (May–June, 1974) or recurred first (beginning November, 1974*) after flooding and also where it was most persistent. The species developed later in the Goodradigbee River arm junction area, but then occurred less densely there than in the other river arm junction areas and was less persistent.

During the eleven collection dates between 14.6.1974 and 18.4.1975 inclusive, when the maximum number of stations was examined regularly, the collections from near Station 3 (Stations 3, 5 and 20) and particularly near Station 6 (Stations 6, 19 and 18) definitely contained *Anacystis* more frequently than did other areas (Table 3). The occurrence of *Anacystis* in Top collections followed a similar pattern.

Furthermore, the only dense occurrences of *Anacystis* in Bottom collections were at Stations 19, 6 and 20, these being at times when the readings of the presence of *Anacystis* were frequent anyway.

Thus the area of development is not a very precisely limited one, but extends in each case over three of the collecting stations. The contrast between the Murrumbidgee and Yass regions on one hand and the Goodradigbee region on the other is obvious. The fact that the areas rich in these algae are fairly extensive makes it even less likely that such an area exists in the Goodradigbee but has not been included in the stations examined. These stations had been chosen as being in corresponding positions for comparison, and the depths of Stations 13, 4 and 14 in the Goodradigbee average 12 to 39 m, certainly overlapping the range of 14 to 32 m of the six stations cited for the Murrumbidgee and Yass areas rich in algae (See Figure 1 and Table 3).

It is interesting to split the total figures given in Table 3 into those of the months February, March, April and May (i.e. those in which there was no *Anacystis* in the Goodradigbee junction area) and the remainder (Table 3). From these totals it appears that *Anacystis* occurs more frequently near the junctions of the Murrumbidgee and Yass Rivers than elsewhere, and, further, this applies irrespective of whether or not one considers those occasions when the species was absent from the Goodradigbee collections but present in the other two river systems.

It is assumed that the plants, arising from these productive areas near the junctions of the rivers, continue to grow and increase while in a plankton form, no doubt aided by the same factors which helped their initial development.

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* These observations are more reliable since the flood had removed surface specimens prior to December.

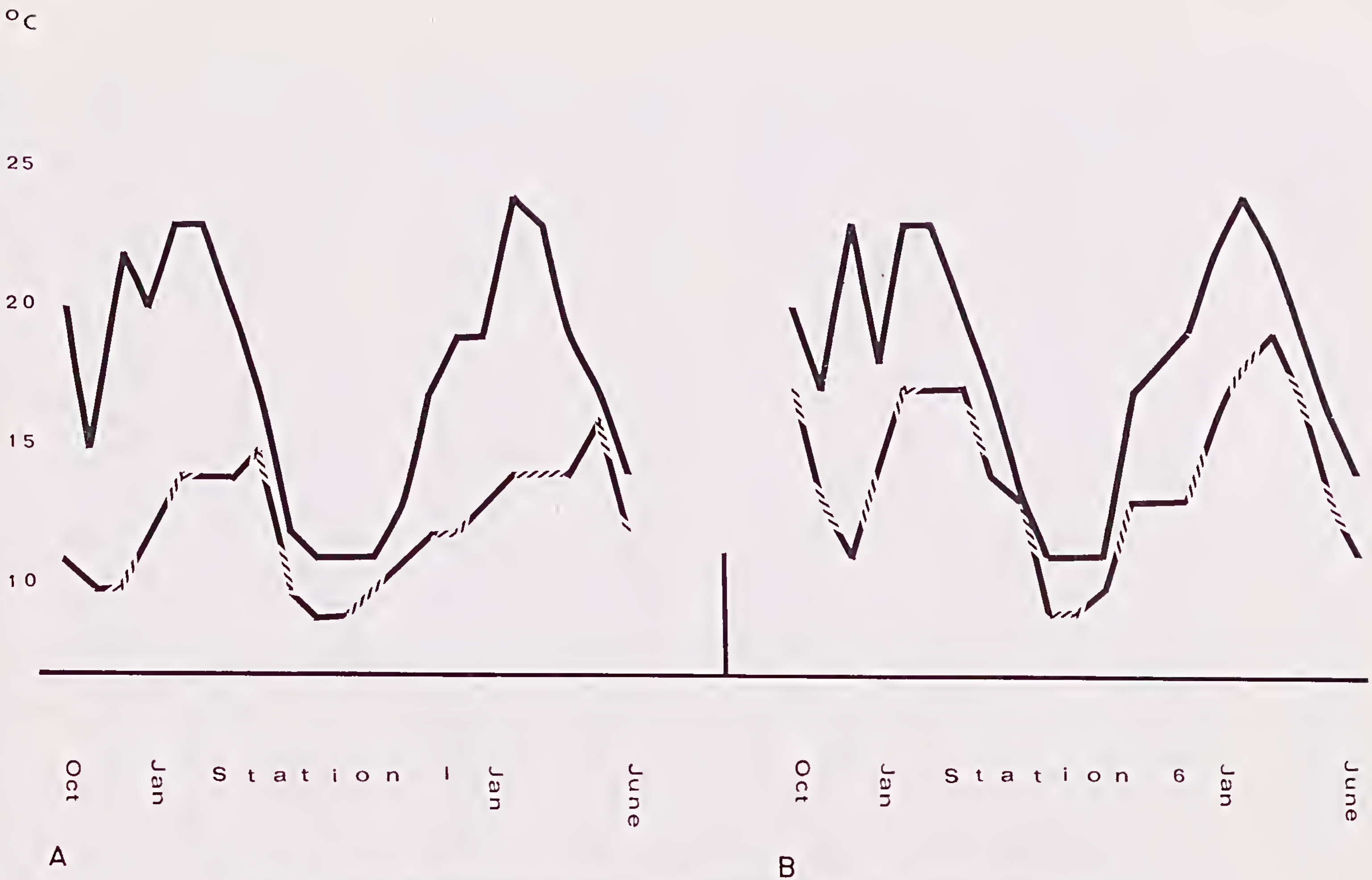

Fig. 2. Graphs showing water temperatures at monthly intervals from October, 1973, to June, 1975. Unbroken line shows Top water temperature. Broken line shows Bottom water temperature. Graph A is of Station 1. Graph B is of Station 6.

Material collected 31.1.1975 at depth of half a metre at Stations 1–6 could be assumed to be less affected by wind than surface collections, but perhaps to reflect the occurrence and growth of the planktonic phase of the growth of *Anacystis*. In these collections *Anacystis* was present in Stations 3 to 6 inclusive, i.e. near the junctions of the river arms. It was noticeably more prevalent in Stations 3 and 5, but still plentiful in Station 6, and less common in Station 4. Highest density of *Anacystis* here again is in the productive areas of the Murrumbidgee and Yass River arm junctions, with less occurring near the Goodradigbee River arm junction.

PHYSICO-CHEMICAL CORRELATION

Physical Factors

Depth of Stations

The collecting stations cited are shown in Figure 1. The average reading (since 13.8.1973 for Stations 1–6, and since 9.7.1974 for Stations 13–20) of their depths is given in Table 3. The depth readings are not precise since there is variation in the water storage level in the dam, the amount of loose sediment lying free, and the exact location of the station (a rock on the river bottom could affect the reading by metres). Stations 1 and 2, nearer the dam wall, are, as expected, markedly deeper than the others. Except for the highest stations upstream, and the Yass River itself, the depths of the other stations do not vary greatly.

Temperature

The Top water showed a range of temperature from about 11° C (winter) to 25° C (summer), whereas Bottom waters showed a winter minimum of about 8° C, but reached a higher summer maximum in shallower collections (Maxima: Stn 1, 15°; Stns 2 and 4, 16°; Stns 3 and 5, 18°; Stn 6, 19°). Thus the difference in temperature between summer Top and Bottom waters was noticeably greater in deep waters, as is to be expected because of stratification. Figure 2, showing the temperature readings of Stations 1 and 6 from October, 1973, to June, 1975, illustrates this difference.

Light Penetration

Observations and estimates made at the time of collecting the water samples show that the light penetration varied with local conditions—ranging from a few cms to about 5 m and was particularly low during the flooding in August to October, 1974. It was generally higher from December to April (i.e. in summer), unless reduced by a bloom. Light penetration was also generally lower in Stations 3, 5 and 6 than in Stations 1, 2 and 4. It would seem that light was likely to be a factor limiting photosynthetic growth in most stations. This possibly favours blue-green as compared with green algae.

Chemical and Biological Factors

The W.C. & I.C.-W.P.C.B. figures on phosphate in 20 serial readings of Bottom water from August, 1973, to February, 1975, display a great deal of variation—

possibly due to variations in input—but the totals of all readings show that Stations 3, 5 and 6 (total readings ranging from 4.22 to 4.98 mg/L) are markedly higher than are those of Station 4 (total readings 3.35 mg/L). Similarly for 21 collections for ammonia nitrogen (in mg/L) the total reading for Stations 3, 5 and 6 ranged from 1.32 to 1.73, compared with those of Station 4, which was 0.35.

The corresponding figures on potassium concentration (in mg/L) obtained by the same analysts show that Stations 3, 5 and 6 also contained higher potassium readings. Thus the total of 16 readings ranged from 33.3 to 34.3 for Stations 3, 5 and 6, compared with 25.1 for Station 4.

Bacterial counts carried out on the six stations of this study showed the *Escherichia coli* count per 100 ml water reached over 100 only in Stations 3, 5 and 6 (in December, 1973, and August, 1974). In addition, total coliform counts per 100 ml water were over 10,000 only in Station 3 (in December, 1973), while faecal *Streptococcus* rose above 100 per ml water only in Station 6 (in May, 1974).

Scribner's examination of twelve stations (both Top and Bottom water) in the dam in November, 1973, and February, 1974, showed that the phosphate levels of Bottom waters (both active and total phosphate) exhibited the expected decrease proceeding from river to dam wall, and showed further that these figures were generally several times greater in the Murrumbidgee and Yass arms, near the river junctions, (total phosphorus November– 75 and 120; February– 66 and 170 μg/L), than in the corresponding areas in the Goodradigbee arm (November– 17 and 17; February– 31 and 37 μg/L). Furthermore he found that the high phosphorus level continued further downstream towards the main dam area in February than in November. Scribner's figures show also very much higher values for iron and nitrite nitrogen near the Murrumbidgee and Yass arm junctions compared with the Goodradigbee arm junction and this effect continued further downstream in summer.

In addition, the dissolved oxygen (whether measured as mg/L or percentage saturation) in Bottom water was generally at least twice as high in the corresponding parts of the Goodradigbee arm as in the Murrumbidgee and Yass arms, which were fairly similar to each other. These values were all lower in summer than in winter. This shortage of oxygen also extended further downstream below the Murrumbidgee and Yass arm junctions in summer than in winter (Scribner's figures).

Thus, summarizing all this chemical information on the analyses of Bottom waters near the junctions of each of the three arms of Burrinjuck Dam, there is a definite contrast, at the areas of the river junctions, between the Murrumbidgee and Yass arms on one hand and the Goodradigbee on the other, the former showing higher nutrient values of phosphorus, nitrite and ammonia nitrogen, iron and potassium, associated with lower oxygen content and sometimes high bacterial counts.

DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

The species *Anacystis cyanea* was collected in New South Wales at least as early as 1915, but it is only since 1966 (McBarron and May) that we have records of its occurrence being in nuisance and toxic quantities.

If one determines that some areas grow greater and nuisance quantities of the toxic alga, while other areas in which it occurs do not, then it seems reasonable to assume that the conditions prevailing in those areas of greater preponderance, but not elsewhere, are those conditions which lead to the excessive growth of the toxic alga.

Anacystis cyanea usually develops during summer in Burrinjuck Dam apparently from Bottom water in areas near the junctions of each of the three tributary rivers, at depths ranging from about 12 to 40 m. The regions near the junctions of the Murrumbidgee and Yass arms have shown excessive growth of toxic algae compared with that of the Goodradigbee arm, which shows only slight growth. The conditions prevailing in the first two cases seem therefore to be those which lead to excessive growth of this alga. In these productive areas there is a high concentration of phosphorus, as well as both nitrite and ammonia nitrogen, potassium and iron, together with low oxygen content and sometimes high bacterial counts. In many ways the Goodradigbee River arm acts as a control contrasted with the polluted (nutrient-enriched) Murrumbidgee and Yass River arms.

The earlier, more frequent, denser and more persistent development of *Anacystis* and possibly early recurrence of *Anabaena* in these productive zones (of the Murrumbidgee and Yass arms) would seem to be associated with the higher nutrient levels of the incoming water and presumably also of the underlying sediments.

The productive areas are those receiving sewage and drainage effluent from upstream urban developments, together with more run-off from pastoral and agricultural land, and this could well account for these changes.

The finding that toxic algae persist or recur in these Bottom collections near the junctions of rivers with the dam—all at depths where light intensity is low, depths ranging from about 12 to 32 m, and with low light penetration,—could be accounted for either as:—

1. an accumulation of these algae deposited from the river load, brought down from upstream, or

2. the algae basically of dam origin, and heterotrophic growth occurring, so that the disintegrated and unrecognizable single cells residual in the sediment are able to grow into recognizable clumps of cells, or

3. an unusually high autotrophic growth efficiency at low light intensities.

However, if, as seems to be definite fact, there is an accumulation of *Anacystis*—in a healthy condition and often showing gas vacuoles—in Bottom collections near the junctions of tributary streams which are high in nutrient (Murrumbidgee and Yass Rivers), then from these zones high concentrations of toxic algae (in fact blooms) could develop either by:

1. heterotrophic growth*, using the high level of nutrients (and probably also of chelating agents) present, increasing the number of algae present, and these algae later rising towards the surface of the water, or

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* Perhaps only indirectly; enhanced bacterial growth leading to local high levels of carbon dioxide and low oxygen and therefore favouring the growth of the algae. This assumes that there is low but sufficient light present.

2. the algae present in the Bottom area rising to a more phototrophic area and then to the surface, possibly carrying a luxury amount of reserve phosphorus (Gerloff and Skoog, 1954) or other inorganic nutrients with them, as suggested by Fogg, (1969). This in turn would assist rapid cell division on reaching the light zone.

In either case the accumulated algae occurring in these Bottom zones near or below the junctions of rivers which bear high nutrients could readily lead to the development of a bloom of the toxic algae. This bloom would then be readily distributed by currents and winds on the surface of the dam.

It is interesting that Chernousova et al. (1968, cited by Whitton, 1973, pp. 360 and 558) also report large deposits of *Microcystis aeruginosa* (= *Anacystis cyanea*) at the bottom of the Kremenchug Reservoir, U.S.S.R., which possibly give rise to the heavy summer development of the algae.

It follows that any treatment of the dam to prevent or control the incidence of blooms of toxic algae in it should be directed towards those areas near the junctions of those tributaries which provide or have provided a heavy nutrient load, i.e. near the junctions of the Murrumbidgee and Yass Rivers in the vicinity of our Stations 3 and 6. This treatment could be directed towards either:—

1. reducing the input of those factors which increase the phosphorus, nitrite and ammonia nitrogen, potassium, iron and bacteria and decrease the oxygen concentrations. It should be borne in mind that there would be a considerable time lag between cessation of such input and cessation of its effect, since there is already likely to be a high reserve accumulated in the sediment, which could be freed under suitable conditions, or

2. altering the conditions at the zones of regeneration and heavy growth of toxic algae, to reduce their suitability as growth zones for the algae concerned. Overseas work indicates that the most hopeful line of work in this field is likely to be by controlled aeration.

Another possible control measure might be to reduce or remove the sediment of re-cycled nutrients in these areas, as has been done physically in Sweden; this might be done physically or chemically. Again, according to whether the species concerned is able to function heterotrophically or not, it might be possible to control it by local reduction of light.

These results and conclusions would seem likely to apply to other similar bodies of impounded water.

ACKNOWLEDGEMENTS

This report is only possible because of the co-operation of many people. The Water Conservation and Irrigation Commission were primarily responsible for the problem being investigated. Their field officer, Mr V. B. Davis, O.I.C., Burrinjuck Dam, has carried out the field collations and observations regularly and well, often under great difficulties: I am most grateful to him.

Results of chemical analyses of the water samples were sent to me by officers of both the Water Conservation and Irrigation Commission and the Water Pollution Control Branch, to whom I wish to express my thanks.

Mr Ted Scribner, of the New South Wales State Fisheries Branch, who has been cngaged in studies on a number of dams, kindly allowed me access to (and permission to cite) some of his physico-chemical results (See pagc 304); for this I am much indebted.

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Notes on Tables

Table 1, A, B and C

Species of algae recorded from Burrinjuck Dam. Stations 1–6 were collected regularly between August, 1973, and April, 1975. Stations 13–20 were collected only between June, 1974, and April, 1975. The station and date of collection are shown for each species. A dash following a date of collection indicates the continuous oecurrence of the species from that date until the next one listed below for that station. Table A. Infrequent speeies. Table B. More common species. Table C. Species which sometimes formed dense blooms.

The authorities for species mentioned in the tables are as follows: *Actinastrum hantzchii* Lag.; *Anabaena circinalis* Rabenh.; *Anacystis cyanea* (Kuetz.) Dr. & Dail.; *Ankistrodesmus falcatus* (Corda) Ralfs; *Ceratium hirundinella* (O. F. Muell.) Dujardin; *Franceia droescheri* (Lemm.) Smith; *Melosira granulata* (Ehrenb.) Ralfs; *Melosira varians* Ag.; *Micrasterias hardyi* West; *Microcoleus lyngbyaceus* (Kuetz.) Crouan; *Scenedesmus obliquus* (Turp.) Kuetz.; *Scenedesmus quadricaudus* (Turp.) de Bréb.; *Schizothrix calcicola* (Ag.) Gomont; *Sphaerocystis schroeteri* Chod.

Table 2.

Record of occurrence of *Anabaena* and *Anacystis* in Top water collections in various stations, showing the change in composition of the algal bloom during the summer of 1973–74.

Table 3.

Table showing the occurrence of *Anacystis* in various Bottom stations during the time when numerous stations were studied (June, 1974, to April, 1975). Results of May, 1974, are included also (six stations only sampled) to complete records for the year but this reading for May may readily be disregarded. These figures are considered both during those times when the species occurred in the Goodradigbee River arm, and those times when it did not. Table also shows depth of stations, showing the average reading in metres. Averages are taken of readings obtained between August, 1973, and May, 1975, for Stations 1 to 6, and between July, 1974, and April, 1975, for stations 13 to 20.

TABLE 1A

	Bottom Samples														Top Samples					
	Main Dam					Murrumbidgee River Area			Goodradigbee River Area			Yass River Area			Main Dam		Murrumbidgee River Area		Goodradigbee River Area	Yass River Area
Species / *Stations:*	1	2	15	16	17	3	5	20	13	4	14	6	19	18	1	2	3	5	4	6
Actinastrum hantzchii	..	8.73 3.74	..	..	..	8.73 10.74	..	..	..	..	..	..	..	..	..	3.74	10.74	10.75	..	10.74
Chlamydomonas sp.	..	..	8.74	..	..	10.74	10.74	..	..	..	..	10.74	..	..	10.74	10.74	10.74	10.74	..	10.74
Chodatella sp.	..	..	..	11.74	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Cosmarium sp.	11.73	..	..	..	..	..	..	..	..	11.73	..	..	..	..	..	..	..	..	..	..
Dictyosphaerium sp.	..	..	..	..	..	..	3.74	..	..	..	..	..	..	..	..	..	..	..	..	..
Euglena sp.	..	..	..	..	..	..	9.74	..	..	12.74	3.75	..	..	9.74 3.75	..	..	..	..	..	11.74
Franceia droescheri	..	..	..	10.74	10.74	..	10.74	..	..	..	..	..	..	..	..	..	..	..	8.73	..
Microcoleus lyngbyaceus	..	2.75	..	..	..	..	..	..	..	..	..	..	2.75	..	..	..	..	2.75	2.75	..
Oedogonium sp.	5.74	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Scenedesmus obliquus	..	..	..	..	..	..	5.75	..	..	..	..	..	..	..	..	..	..	10.74	..	..
Scenedesmus quadricaudus	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	10.74	..	..	..
Schizothrix calcicola	..	..	10.74	..	..	..	..	..	..	..	..	..	..	..	..	..	2.74	..	6.74	..
Selenastrum sp.	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	10.74	..	..	..
Spirogyra sp.	..	..	4.75	..	..	3.75	..	..	..	..	..	..	..	..	..	..	..	..	2.74	..
Spondylosium sp.	..	9.73	..	..	..	..	..	..	..	9.73	..	..	..	..	1.74	..	..	..	..	..
Tetradron sp.	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	11.74	..	..	..
Unidentified filamentous (damaged) algae.	..	..	..	..	2.75 3.75	10.74	8.74	..	10.74	5.74 12.74	12.74 2.75 3.75	..	..	10.74 3.75	..	10.74	..	9.74	..	9.74
Volvox sp.	..	..	..	..	..	..	..	..	..	..	..	2.75	..	..	2.74	..	..	..	11.73	..

TABLE 1C

	Bottom Samples														Top Samples					
	Main Dam					Murrumbidgee River Area			Goodradigbee River Area			Yass River Area			Main Dam		Murrumbidgee River Area		Goodradigbee River Area	Yass River Area
Species / *Stations:*	1	2	15	16	17	3	5	20	13	4	14	6	19	18	1	2	3	5	4	6
Anabaena circinalis	12.73 3.74	11.73 12.73	..	..	..	..	2.74	..	..	11.73 6.75	11.73 7.74	8.73 3.74 3.75	..	..	10.73– 12.73 5.74	11.73 12.73	11.73 2.74	..	10.73 11.73	8.73 9.73 2.74 5.74
Anacystis cyanea	12.73 1.74 3.74 4.74 6.74	11.73– 2.74 4.74 1.75 5.75 6.75	2.75	2.75	..	12.73– 2.74 4.74 6.74 11.74 1.75 3.75 5.75 6.75	12.73– 2.74 6.74 1.75– 3.75	2.74 6.74 7.74 1.75 3.75 4.75	12.74	11.73– 1.74 4.74 7.74 1.75	6.74 7.74 1.75	1.74 3.74 5.74– 7.74 12.74– 4.75 6.75	2.74 6.74 7.74 1.75– 4.75	6.74 7.74 1.75– 3.75	10.73– 2.74 5.74 6.74 1.75 2.75	11.73– 2.74 4.74 12.74 2.75	11.73– 4.74 1.75– 3.75 5.75	11.73– 5.74 8.74 1.75 2.75	11.73– 2.74 4.74 6.74 12.74 2.75	12.73– 3.74 5.74– 7.74 12.74– 5.75

TABLE 1B

Species	Bottom Samples: Main Dam					Murrumbidgee River Area			Goodradigbee River Area			Yass River Area			Top Samples: Main Dam		Murrumbidgee River Area		Goodradigbee River Area	Yass River Area
Stations:	1	2	15	16	17	3	5	20	13	4	14	6	19	18	1	2	3	5	4	6
Ankistrodesmus falcatus	5.74 6.74	4.74 6.74– 8.74 10.74	7.74	8.74	6.74 8.74	8.74 6.75	6.74 8.74– 10.74	6.74– 9.74	6.74 7.74 10.74	8.74 9.74	2.74 6.74 7.74	6.74 8.74 2.75 6.75	6.74– 8.74	6.74– 9.74	5.74 6.74 8.74– 10.74 6.75	4.74 8.74 10.74	6.74 8.74 10.74 6.75	6.74 8.74 10.74 11.74 2.75 6.75	6.74– 10.74 3.75	5.74 6.74 8.74 10.74 4.75
Ceratium hirundinella	3.75	4.74	..	..	3.75	11.73	..	6.74 8.74	3.75	3.75	..	..	6.74 7.74	6.74 4.75	..	4.74	11.73	..	3.74 9.74	2.75 3.75
Closterium sp.	11.73	9.73 11.73	7.74	..	7.74	7.74 8.74	9.73 7.74	..	11.73 8.74	7.74	7.74	..	..	..	7.74	11.73 7.74	7.74	7.74	7.74	9.73 10.73 7.74
Cyclotella sp.	9.74	10.74 4.75	..	..	10.74	10.74 6.75	9.74 10.74 6.75	..	10.74	4.75 5.75	10.74	10.74 6.75	..	9.74– 10.74	6.74 10.74	9.74 10.74 4.75	8.74 10.74 6.75	10.74 6.75	9.74	10.74 11.74 6.75
Diatoms (various species)	3.75	3.74 7.74 8.74 2.75	2.74 7.74	2.74 7.74 9.74 10.74 4.75	2.74 6.74– 10.74	4.74 6.74 8.74 10.74 5.75	4.74 6.74 9.74– 11.74 5.75	2.74 9.74– 11.74 2.75 3.75	7.74 9.74 10.74	2.74 6.74 8.74 10.74 11.74	11.73 7.74 9.74– 11.74 1.75 4.75	3.74 7.74– 11.74 4.75– 6.75	11.73 2.74 7.74 9.74– 11.74 4.75	6.74– 3.75	5.74 9.74– 11.74	8.74	2.74 9.74 10.74	8.74– 10.74 6.75	3.75	7.74 9.74– 11.74 6.75
Melosira granulata	8.73– 7.74 9.74 10.74 1.75– 6.75	8.73– 7.74 9.74 10.74 3.75– 6.75	11.73 6.74– 9.74 3.75 4.75	11.73 6.74– 9.74 12.74 3.75 4.75	11.73 6.74 7.74 9.74 11.74 12.74 3.75 4.75	8.73 9.73 11.73– 9.74 11.74 2.75– 6.75	8.73 9.73 12.73– 9.74 12.74 2.75– 6.75	6.74– 10.74 12.74 3.75 4.75	11.73 7.74 1.75– 4.75	8.73– 9.74 11.74– 6.75	6.74– 8.74 11.74 1.75– 4.75	8.73 9.73 12.73– 9.74 2.75– 6.75	11.73 6.74– 9.74 11.74 3.75 4.75	6.74– 8.74 10.74 1.75– 4.75	8.73– 3.74 5.74 7.74 8.74 3.75– 6.75	9.73– 9.74 3.75– 6.75	8.73– 10.73 1.74– 9.74 3.75– 6.75	8.73 9.73 1.74– 5.74 7.74– 9.74 3.75– 6.75	8.73– 11.73 1.74– 10.74 3.75– 6.75	8.73 10.73 1.74 3.74– 7.74 9.74 10.74 3.75– 6.75
Melosira varians	4.74– 12.74 2.75– 6.75	4.74– 12.74 4.75– 6.75	6.74– 1.75 3.75 4.75	6.74– 11.74 3.75 4.75	6.74– 4.75	4.74– 12.74 3.75– 6.75	4.74– 12.74 3.75– 6.75	2.74 6.74– 12.74 3.75 4.75	6.74– 12.74 4.75	5.74– 1.75 4.75– 6.75	6.74– 11.74 1.75 2.75 4.75	4.74– 12.74 3.75– 6.75	6.74– 11.74 3.75 4.75	6.74– 4.75	4.74– 11.74 1.75 4.75– 6.75	4.74– 12.74 4.75– 6.75	2.74 4.74– 12.74 3.75– 6.75	4.74– 12.74 2.75– 6.75	4.74– 10.74 3.75– 6.75	4.74– 12.74 3.75– 6.75

TABLE 1B—*continued*

	Bottom Samples														Top Samples					
	Main Dam					Murrumbidgee River Area			Goodradigbee River Area			Yass River Area			Main Dam		Murrum-bidgee River Area		Goodradig-bee River Area	Yass River Area
Species *Stations:*	1	2	15	16	17	3	5	20	13	4	14	6	19	18	1	2	3	5	4	6
Micrasterias hardyi	11.73 3.75 4.75	7.74 3.75	8.74 3.75	3.75	3.75 4.75	8.74 3.75	6.74	..	11.73 3.75	7.74 3.75	2.75– 4.75	3.75	3.75	..	5.74	4.74 5.74 2.75 3.75	..	7.74 3.75	6.74 3.75	..
Oocystis sp.	9.73 11.73 2.74	9.73 4.74 8.74 9.74 5.75	9.74 1.75	7.74 2.75	..	7.74 5.75	9.73	..	9.74	5.75	2.74 9.74 2.75 4.75	8.73 4.74 6.75	9.74	4.75	11.73 1.74 2.74	11.73 1.74 2.74 11.74 6.75	2.74 4.74	9.73 10.74 6.75	8.73 11.73 12.73 2.74 9.74	8.73 3.74– 5.74 7.74 9.74
Pandorina sp.	..	8.74 6.75	..	9.74 10.74	10.74	..	10.74 4.75 6.75	10.74	10.74	9.74	3.75	10.73 10.74 4.75 6.75	..	4.75	10.74 4.75	2.74 8.74 10.74 3.75	8.74 10.74 4.75 6.75	10.73 10.74 3.75 6.75	8.74– 10.74 4.75 6.75	10.74 4.75
Sphaerocystis schroeteri	11.73	11.73 4.74	12.74 3.75	6.74 3.75	..	11.74 12.74	12.74	6.74 12.74	12.74	6.74 12.74	11.73 2.74 6.74 7.74 12.74 2.75	11.74	12.74	6.74 7.74	11.73 2.74 12.74	11.73 2.74 12.74 3.75	11.73 2.74– 5.74 11.74 12.74	7.74 12.74 3.75	11.73 2.74 12.74 2.75 3.75	12.74
Staurastrum sp.	8.73– 11.73 2.74– 6.74 3.75	8.73– 1.74 3.74 4.74 6.74 7.74 9.74 3.75– 5.75	11.73 6.74– 8.74 3.75 4.75	7.74 3.75 4.75	6.74 7.74 3.75 4.75	8.73– 11.73 1.74– 8.74 11.74 5.75 6.75	8.73 9.73 2.74 3.74 5.74– 8.74 12.74 4.75– 6.75	6.74– 8.74 4.75	11.73 6.74 7.74 3.75 4.75	8.73 9.73 12.73 2.74 3.74 5.74– 9.74 3.75– 6.75	2.74 6.74– 8.74 1.75 3.75 4.75	8.73– 10.73 1.74– 7.74 4.75 6.75	6.74 7.74 9.74 3.75	2.74 6.74 7.74 3.75 4.75	8.73– 11.73 1.74– 8.74 10.74 3.75– 6.75	8.73 9.73 11.73 1.74– 6.74 9.74 3.75 5.75 6.75	8.73 9.73 12.73 2.74 4.74– 6.74 4.75– 6.75	8.73– 10.73 2.74– 5.74 7.74– 9.74 5.75 6.75	8.73 9.73 11.73– 6.74 8.74 9.74 3.75– 6.75	8.73 9.73 12.73 3.74– 6.74 3.75– 6.75
Trachelomonas sp.	7.74	3.75 4.75	9.74 3.75	9.74 4.75	8.74 11.74 3.75	8.74 10.74	7.74 8.74 10.74 11.74 3.75	6.74– 8.74 11.74	..	2.74 6.74 7.74 5.75	2.74 6.74 7.74 2.75 3.75	7.74 9.74 12.74 3.75	2.74 6.74– 8.74	2.74 9.74– 11.74 1.75– 4.75	7.74 9.74 10.74 3.75	9.74– 11.74	2.74 6.74 7.74 9.74– 11.74 2.75 3.75 6.75	7.74– 12.74 2.75 3.75 6.75	7.74 9.74 10.74 3.75	4.74 6.74– 10.74 12.74 3.75 5.75

TABLE 2.

Top Collections of *Anabaena* and *Anacystis*, Summer 1973-4

Date	*Anabaena*	*Anacystis*
–/7/73	Stn 3	
–/8/73	Stn 6	
–/9/73	Stn 6	
–/10/73	Stn 1,4	Stn 1
–/11/73*	Stn 1,2,3,4	Stn 1,2,3,4,5
–/12/73	Stn 1,2	Stn 1,2,3,4,5,6
–/1/74†	—	Stn 1,2,3,4,5,6
–/2/74	Stn 3,6	Stn 1,2,3,4,5,6
–/3/74	—	Stn 3,5,6
–/4/74	—	Stn 2,3,4,5
–/5/74	Stn 1,6	Stn 1,5,6
–/6/74	—	Stn 1,4,6
–/7/74	—	Stn 6
–/8/74	—	Stn 5
–/9/74 } Flood		
–/10/74 } Flood		

* Maximum growth of *Anabaena*

† Maximum growth of *Anacystis*

TABLE 3

Occurrence of *Anacystis* in Bottom water collections, 1974–1975

Area:	Main Dam					Murrumbidgee River Area			Goodradigbee River Area			Yass River Area		
Station Number:	1	2	15	16	17	3	5	20	13	4	14	6	19	18
Water depth (m):	48	45	38	34	35	32	29	14	39	35	12	24	17	24
Collection Date														
May, 1974												x		
June	x					x	x	x			x	x	x	x
July								x		x	x	x	x	x
August														
September														
October														
November						x								
December									x			x		
January, 1975		x				x	x	x		x	x	x	x	x
February			x	x			x					x	x	x
March						x	x	x				x	x	x
April, 1975								x				x	x	
Total number of occurrences during February to April, 1975 and also May, 1974	0	0	1	1	0	1	2	2	0	0	0	4	3	2
Total number of occurrences except during above months	1	1	0	0	0	3	2	3	1	2	3	4	3	3
Total number of occurrences	1	1	1	1	0	4	4	5	1	2	3	8	6	5